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INJECTION OF PARTICLES THROUGH A JET NOZZLE LATERALLY INTO A SUPERSONIC AIRSTREAM

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ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

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INJECTION OF PARTICLES THROUGH A JET NOZZLE LATERALLY INTO A SUPERSONIC AIRSTREAM

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ARO, Inc.

a subsidiary of Sverdrup and Parcel, Inc.

September 1964

ARO Project No. VD0459

ABSTRACT

Tests were conducted in the 12-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to determine the particle distributions downstream of a nozzle exhausting particle-laden flow laterally into the airstream from the tunnel floor.

Data were obtained at Mach 3 for a range of jet pressure ratios and nozzle sizes with the nozzles located at several positions upstream of the sampling rake. Reynolds number ranged from 0.15 to 0.62×10^6 per inch. Selected results are presented.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

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NOMENCLATURE

d_j	Nozzle diameter, in.
M_∞	Free-stream Mach number
m	Weight of particle sample, mg
m_{max}	Maximum particle sample weight, mg
p_o	Tunnel stagnation pressure, psia
p_{o_j}	Jet chamber pressure, psia
p_∞	Free-stream static pressure, psia
Re	Reynolds number
x_p	Distance from probe leading edge to nozzle centerline, in.
y	Vertical coordinate, in.

1.0 INTRODUCTION

At the request of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), particle injection tests were conducted in the Gas Dynamic Wind Tunnel, Supersonic (D), of the von Kármán Gas Dynamics Facility (VKF), Arnold Engineering Development Center (AEDC), AFSC, for the Vought Aeronautics Division of Ling-Temco-Vought, Inc. (LTV). The objective of the tests was to determine the distribution at several downstream locations of particles injected laterally into a supersonic airstream. The tests were made at Mach number 3 over a range of jet pressure ratios, p_{o_j}/p_∞, from 60 to 245 at nozzle positions from 2.80 to 24.75 in. upstream of the sampling rake. Nozzle sizes were varied from 0.0995 to 0.221 in. diameter. Tunnel Reynolds number ranged from 0.15 to 0.62 x 10^6 per inch.

The tests were conducted during the period from May 25 to June 10, 1964.

2.0 APPARATUS

2.1 WIND TUNNEL

Tunnel D (Fig. 1) is an intermittent, variable-density wind tunnel with a manually adjusted, flexible plate-type nozzle and a 12- by 12-in. test section. The tunnel operates at Mach numbers from 1.5 to 5 at stagnation pressures from about 5 to 60 psia and at stagnation temperatures up to about 80°F. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook.*

2.2 TEST EQUIPMENT

The test equipment (Figs. 2 and 3) was furnished by LTV and consisted of a sonic jet nozzle mounted flush with the tunnel floor with a thirteen-probe sampling rake located downstream of the nozzle. An additional probe, designated as the "control probe", was mounted in the tunnel roof to provide data on background contamination in the tunnel air supply (see Fig. 2). Three different nozzle sizes, 0.0995-, 0.15-, and 0.221-in. diameters, were tested at four different positions

*Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

Manuscript received August 1964.

upstream of the rake (see Fig. 3b). The nozzle and rake were positioned on the tunnel centerline, with the rake also being positioned 1.10 and 1.72 in. off-center.

A particle injection system (Fig. 3c), consisting of a high pressure nitrogen gas supply and a disseminator, was connected to the nozzle. The disseminator was a hollow cylinder with two diametrically opposed nitrogen inlets tangent to the cylinder walls. In the operation of the disseminator, the arrangement of the inlets caused a vortex to be created by the nitrogen flow, which disrupted a column of uncompacted magnesium silicate (talc) which has a particle size of 1 to 5 micron diameter. The gas entrained the particles, and the particle-gas mixture was injected into the tunnel through the nozzle.

The sampling rake was connected to a filter system (Fig. 3d) and a vacuum source outside of the tunnel. The probes of the rake were, in effect, small normal shock inlets, and these were calibrated to ensure that their flow rates were approximately the same when the vacuum system was on. The filter system included a filter for each probe and a valve assembly, containing a valve for each probe, which automatically switched the flow to or from the filters and allowed an accurately timed sample to be taken. The filters were of a "Fiberglas" material and were designed to trap particles of less than one micron diameter.

2.3 INSTRUMENTATION

Pitot pressures were measured with the Tunnel D standard pressure-scanning system using 15-psid transducers referenced to a near vacuum. The 15-psid transducers were calibrated for ranges of 15, 7.5, and 3 psia. The precision of the system is estimated to be within one percent of the ranges being used. The particle samples were weighed with a digital balance with a sensitivity of 0.1 mg. This balance was estimated to be accurate within ±0.05 mg.

3.0 PROCEDURE

Each combination of nozzle size, nozzle position, and rake position was run at the test conditions shown on the following page.

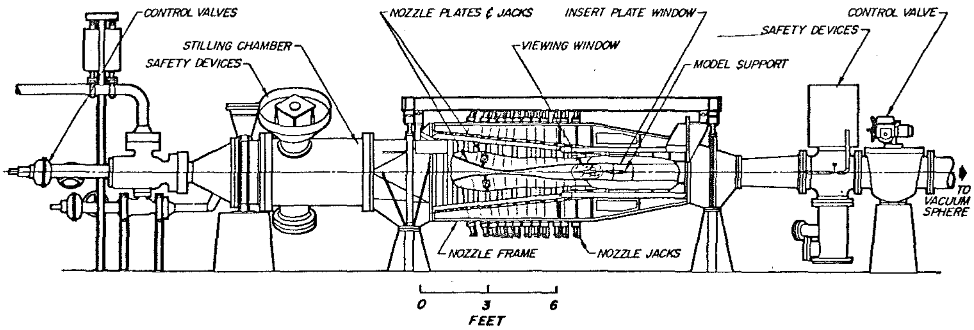
p_{o_j}/p_∞	p_o, psia	Re/in. x 10^{-6}
245	11.0	0.15
120	22.5	0.31
60	45.5	0.62

Before the sampling tests, the rake was connected to the tunnel pressure-scanning system to obtain pitot pressure profiles at each downstream location with nitrogen flow only from the nozzle at the various jet pressure ratios. A typical sampling run consisted of the following:

1. After tunnel flow was established, injection of nitrogen-gas-talc mixture was stabilized at the appropriate jet pressure ratio.
2. Flow was passed through filters for a timed sample.
3. Dissemination of particles-gas mixture was stopped.
4. Filters were removed for gravimetric analysis.

4.0 RESULTS AND DISCUSSION

Particle distributions on the tunnel centerline at $M_\infty = 3$ for selected values of jet pressure ratio, nozzle size, and nozzle position are given in Fig. 4, and these are representative of the results from all other conditions. These distributions are presented as the ratio of particle weight from each probe to the maximum particle weight obtained from any probe for a particular sampling run. The results shown indicate that the greatest concentration of particles occurred outside the tunnel boundary layer. Figure 4a, which presents distributions obtained at various locations, shows that the particle concentration moves closer to the wall as the distance from the nozzle increases. This trend can also be seen from the accompanying shadowgraph. Increasing the jet momentum by increasing the pressure ratio (Fig. 4b) or the nozzle diameter (Fig. 4c) increased the depth of particle penetration into the free stream.



Assembly

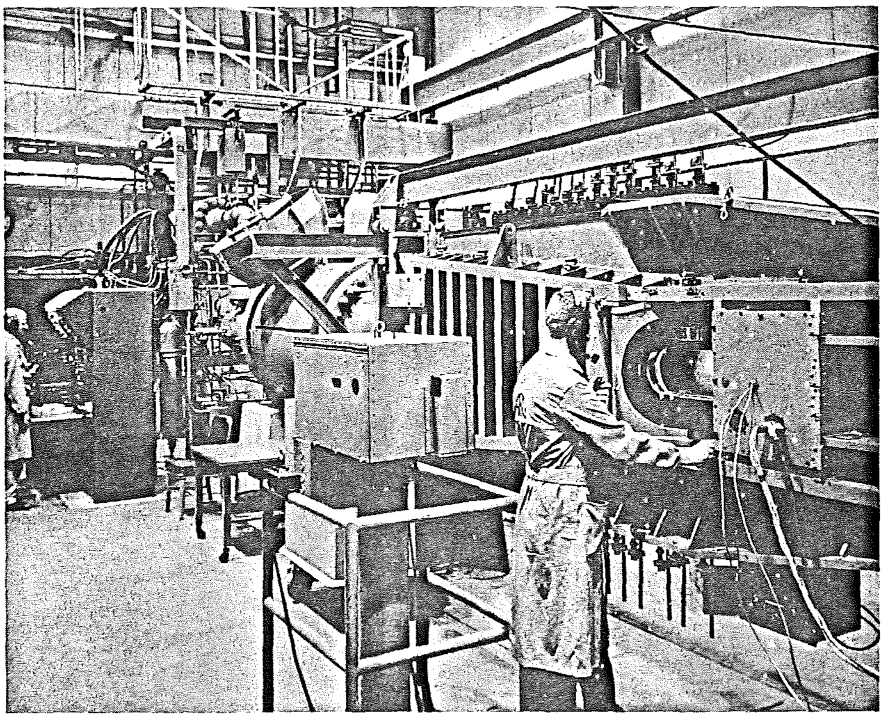


Fig. 1 Tunnel D

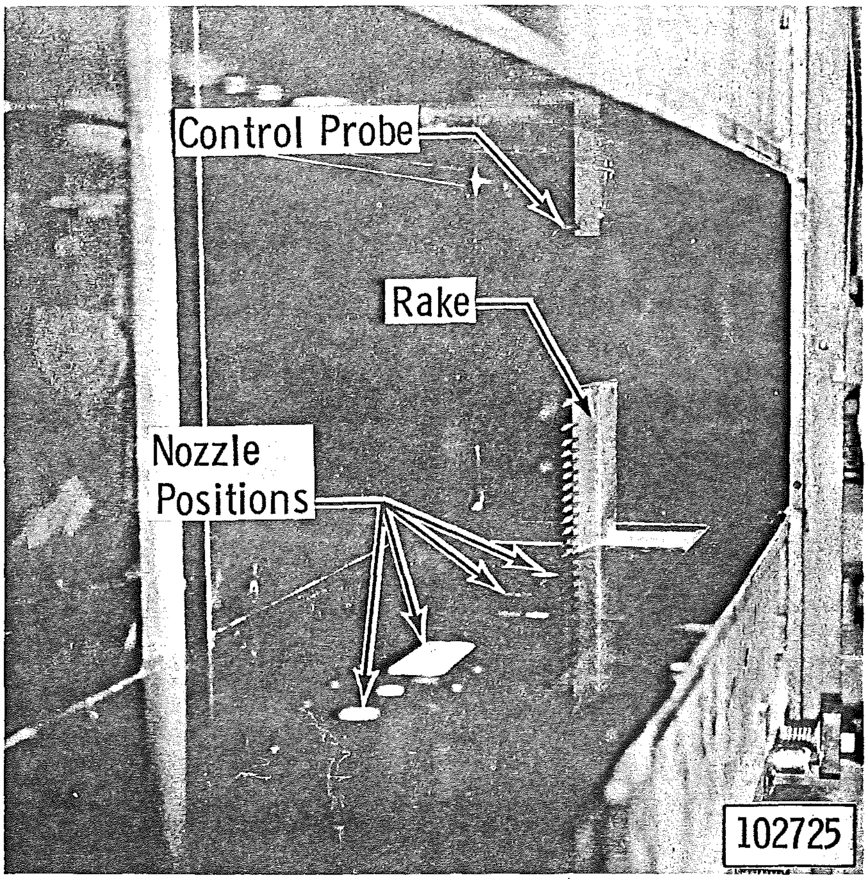
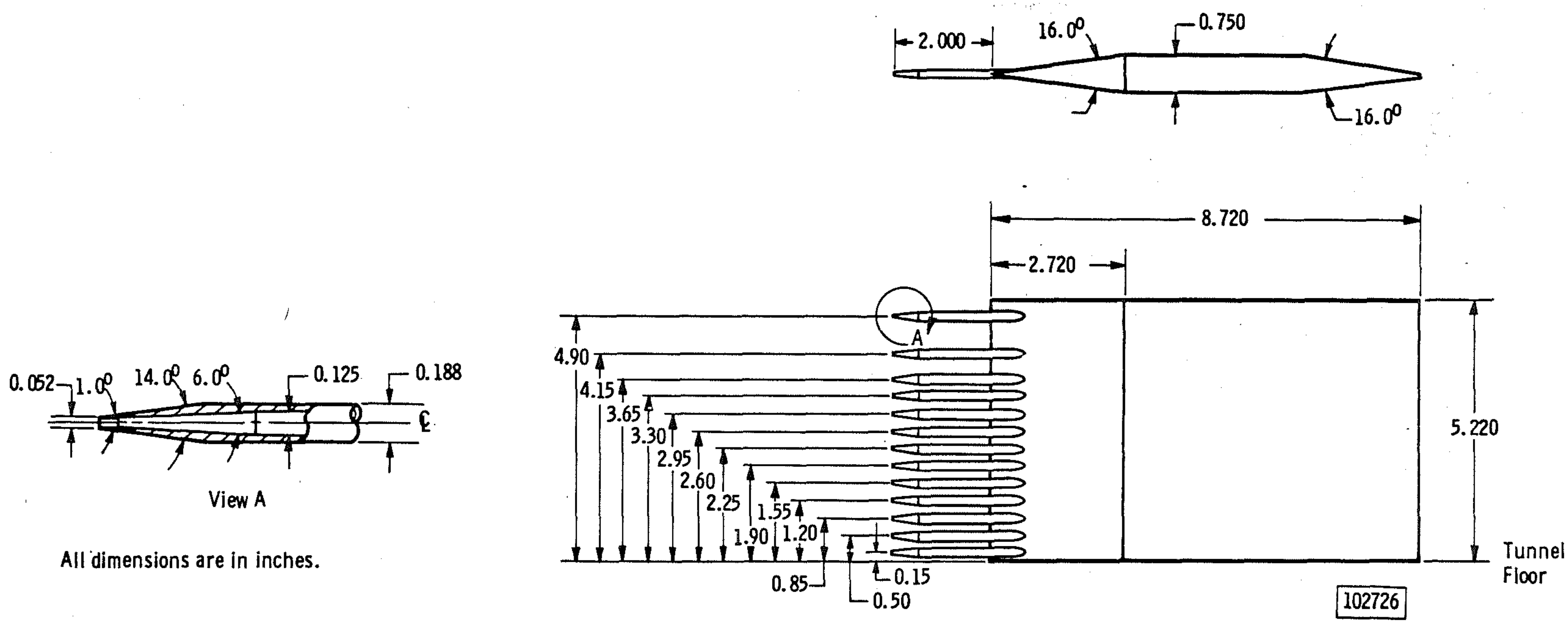
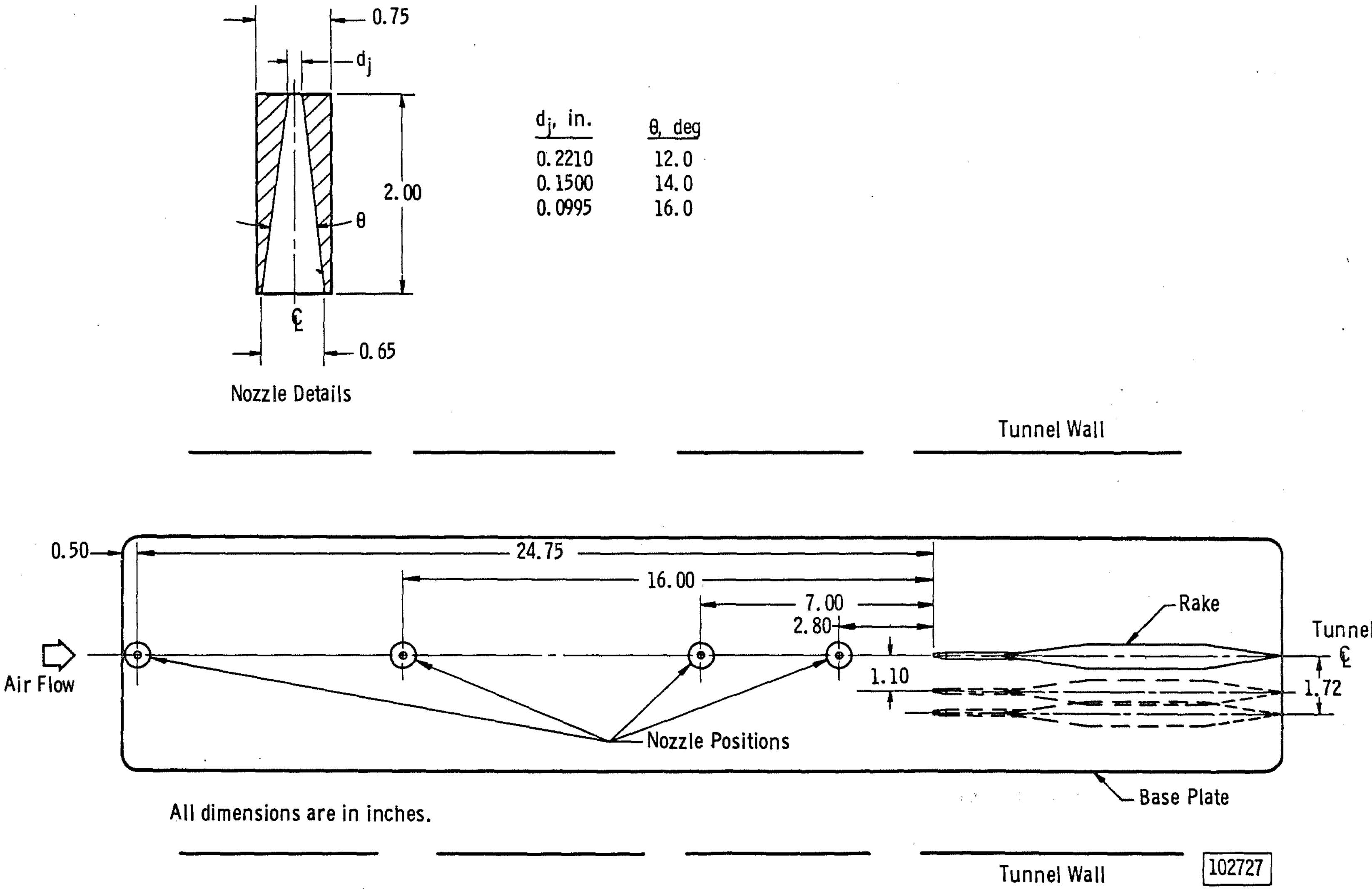


Fig. 2 Nozzle and Sampling Rake



a. Sampling Rake Details

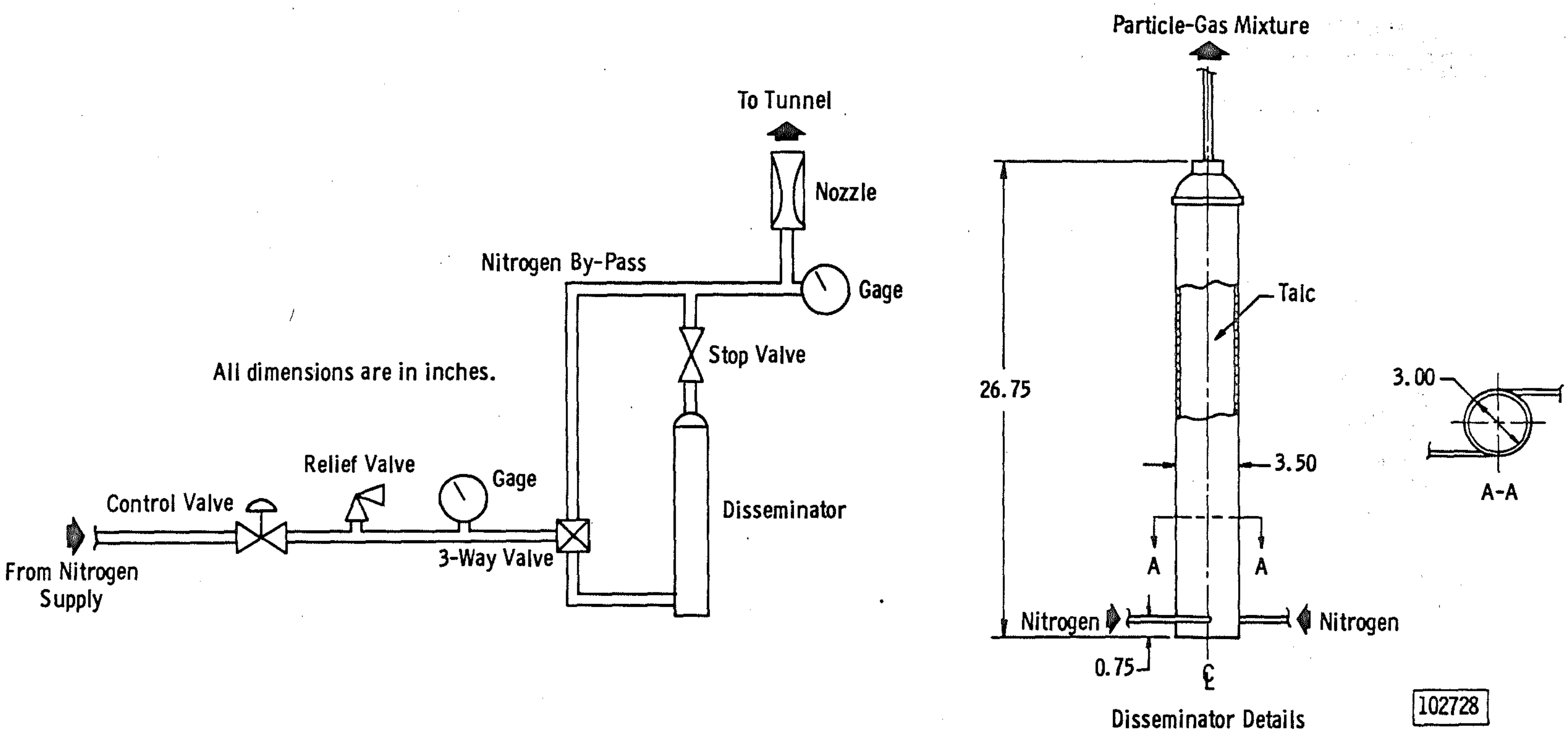
Fig. 3 Test Equipment



d_j, in.	θ, deg
0.2210	12.0
0.1500	14.0
0.0995	16.0

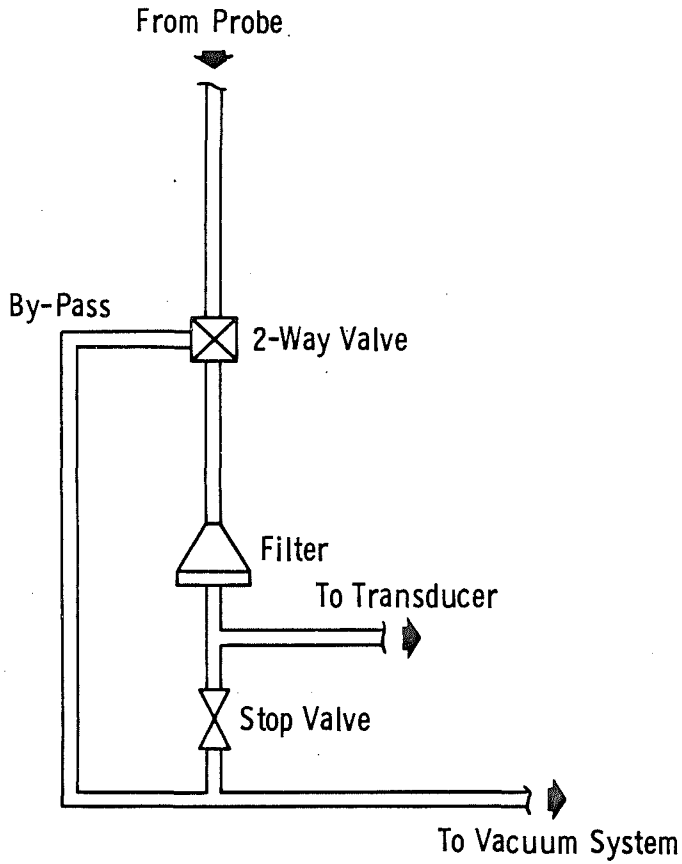
b. Nozzle and Sampling Rake Locations

Fig. 3 Continued

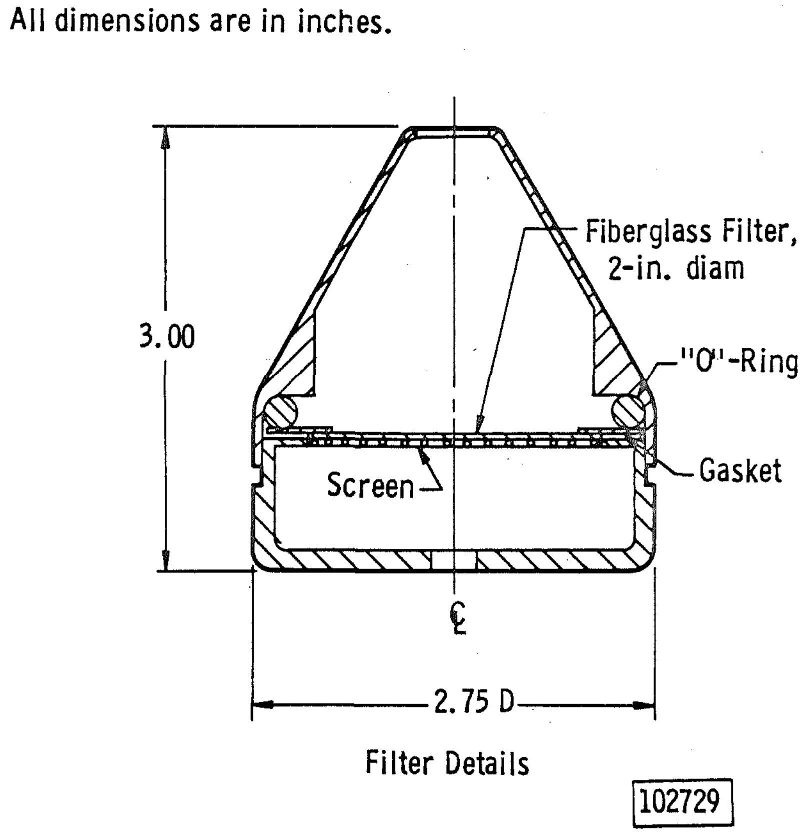


c. Particle Injection System

Fig. 3 Continued



Note: There were fourteen filters, one for each probe on the rake and the "control probe."

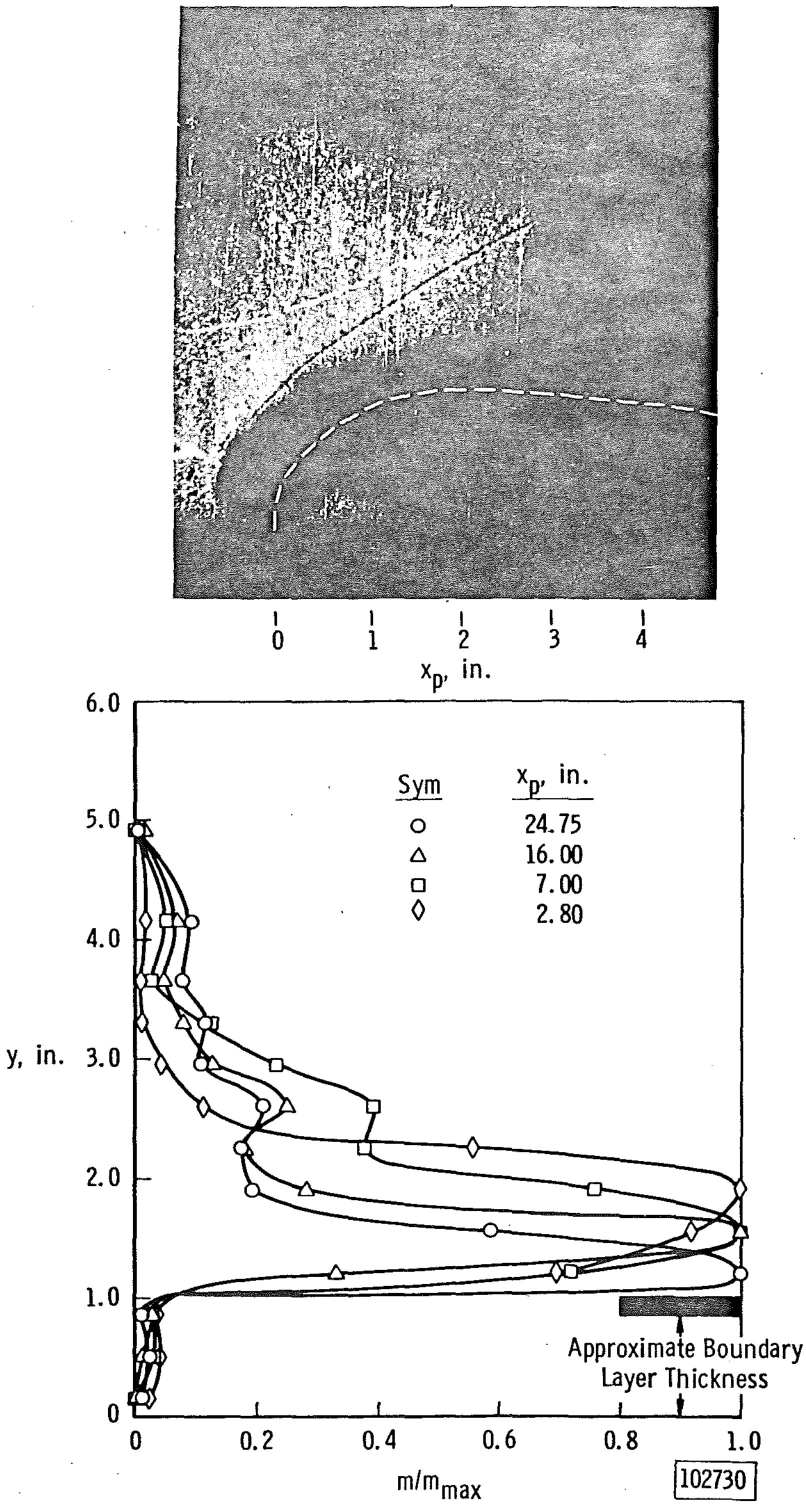


Filter Details

102729

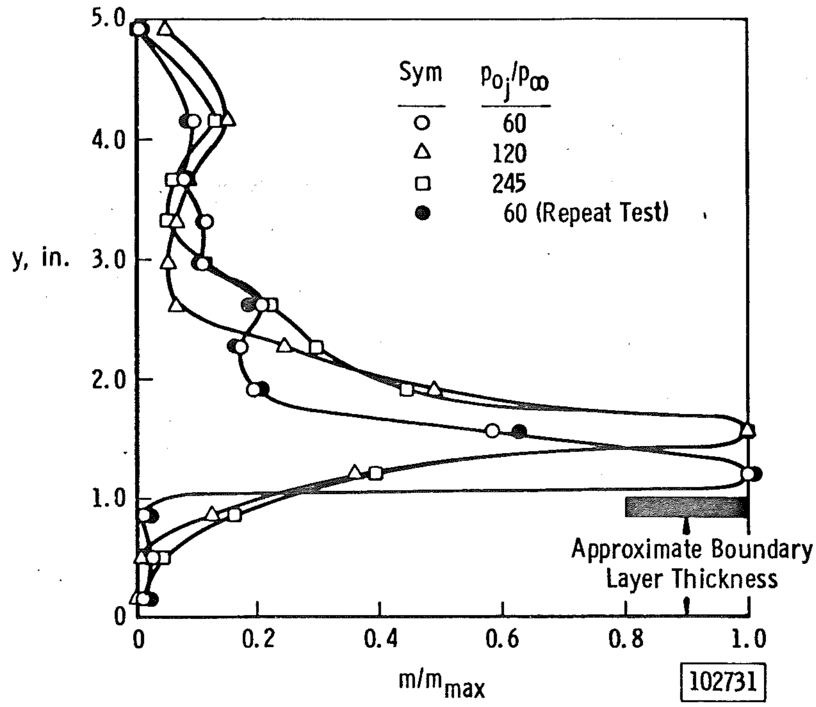
d. Filter System

Fig. 3 Concluded

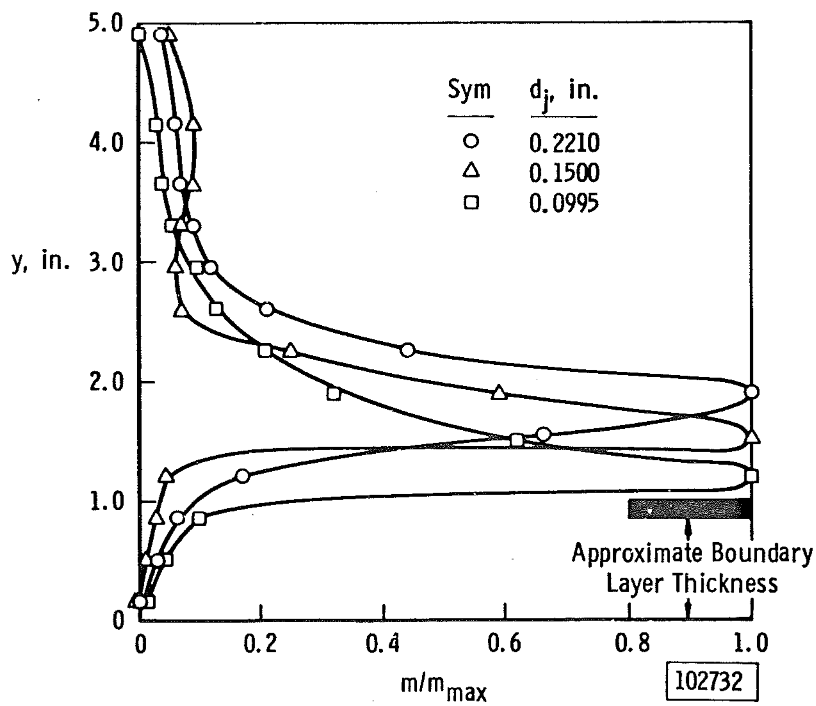


a. Variation of Nozzle Position; $d_j = 0.15$ in., $p_{o_j}/p_\infty = 60$

Fig. 4 Particle Distribution on Tunnel Centerline at $M_\infty = 3$



b. Variation of Jet Pressure Ratio; $d_j = 0.15$ in., $x_p = 24.75$ in.



c. Variation of Nozzle Diameter; $p_{o_j}/p_\infty = 120$, $x_p = 24.75$ in.

Fig. 4 Concluded